Tracking dynamics of retrodirective vehicle RADAR with track hold ability

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Keywords: Radar, Radar tracking, Antenna arrays, Adaptive Arrays.

Abstract

This paper considers the tracking dynamics of a retrodirective RADAR when applied to a vehicular scenario. The advantages of such a RADAR system are discussed in comparison to a conventional RADAR. More specifically, a "track hold" function is presented for a retrodirective RADAR, which is shown, for typical vehicle turning rates, to be able to maintain the retransmitted beam towards the target during dropouts in the reflected signal. These dropouts could be caused by effects such as variations of target radar cross section with angle of incidence. The "track hold" feature prevents the need for a reacquisition of the target after the dropout and also provides the possibility of using the RADAR to reliably transmit data to the target. The ability to provide a reliable retransmitted beam, even in the absence of a target reflected signal, is a significant improvement compared to traditional mixer based retrodirective antennas, which are unable to maintain the retransmitted signal in the absence of a received signal.

1 Introduction

Retrodirective RADAR has the advantage of fast acquisition and tracking of a target using relatively simple circuits. There is no requirement for mechanically, or electronically scanned directional antennas as would be the case in a conventional RADAR. In conventional RADAR, a directional antenna is scanned, by mechanical or electronic means, and a pulsed signal is transmitted, with the return (echo) signal providing the range information. Direction information is obtained from the position of the scanning antenna, or computed angle of arrival, at the time the return pulse from a target was received. In a retrodirective RADAR there is no requirement to mechanically, or electronically, scan the antenna, since the target is acquired simply by a phase conjugation process that ensures that the maximum retransmitted beam is always focused onto the target. The retransmitted phase values can then be used to calculate the position of the target. During the absence of a target the retrodirective RADAR transmits a broad illumination, but can quickly reacquire, and refocus the beam when a target appears in the field of view.

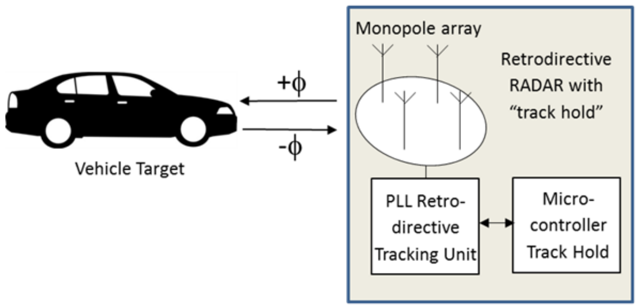
One major advantage of the retrodirective RADAR is the speed and simplicity of tracking, since, once the RADAR has acquired the target, it stays locked to it, rather than continuously scanning as is the case of a conventional RADAR, where the tracking speed would be limited by the scanning speed. It has been shown that a retrodirective RADAR can track fast moving targets (of up to 780 ms) [1]. The retrodirective RADAR has also been practically shown to successfully detect the position of near field targets [2].

In this paper we look at the aspects behind applying a retrodirective RADAR to a vehicular scenario. In this application mass produced retrodirective RADARs can benefit from simple circuitry, which is typically small enough to be incorporated entirely within the space occupied by the antenna array. One of the main challenges that will be addressed in this paper is the ability of the retrodirective RADAR to continuously stay locked to a target (using a track hold function), even if dropouts are received from the reflected signal. Such dropouts could occur due to variations in the targets' radar cross section (RCS) with azimuth angle. The advantage of having the retrodirective RADAR continuously locked to the target, even during reflected signal dropouts, provides for consistent tracking with no reacquisitions needed. The retrodirective antenna has also been previously shown to be able to operate with modulated signals [3], that have little, or no effect on the retrodirective operation, meaning that the RADAR could also be used to reliably transmit/receive data to the target without any interruptions to the retransmitted beam. The applications of this retrodirective RADAR are particular pertinent due to the potential widespread use of autonomous vehicles.

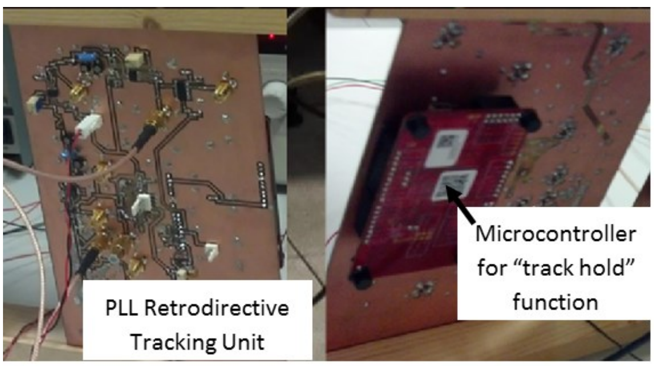
2 Retrodirective RADAR with "Track Hold" function

In this section the tracking dynamics of a retrodirective RADAR applied in a vehicular RADAR scenario are studied. In particular, the effects on the retrodirective RADAR tracking ability if a dropout is received on the reflected signal from the target. A likely cause of such a dropout is the variation of RCS of the target as the angle of incidence is varied. Considerable measured data showing this phenomenon is available (eg [4]). This measured data shows the reflected signal from a vehicle can vary by up to 40 dB over the measured azimuth range. Typically the highest reflected signal is experienced when most of the flat panels of the vehicle are at normal incidence to the RADAR and will reduce significantly as the RADAR is moved away from normal incidence.

Employing a traditional (mixer based) retrodirective RADAR [5] would mean that the tracking ability is almost instantly lost during the dropout of a reflected signal since the mixer based architecture cannot maintain the transmit signal direction in the absence of received signal. More recently QUB has provided improvements to the traditional mixer based retrodirective antennas by the addition of a tracking PLL [6]. PLL based retrodirective antennas can offer some degree of “flywheel” effect when a dropout is received, which provides some ability to hold the tracking position, until the target signal reappears. Hold times of up to 0.27 µs have been practically shown in pulsed retrodirective RADARs [7]. Longer hold times could be possible by using slower time constant loop filters, but would still be likely to be restricted to periods of several ms. Newer development to this PLL architecture, shown in Fig 1, involves adding a microcontroller to the tracking loop, which provides a “track hold” function of several seconds. Other advantages of this approach, include straightforward obtaining of the target position information, as this is easily calculated from the array phase information from the microcontroller.



(a) Retrodirective RADAR with track hold – block diagram



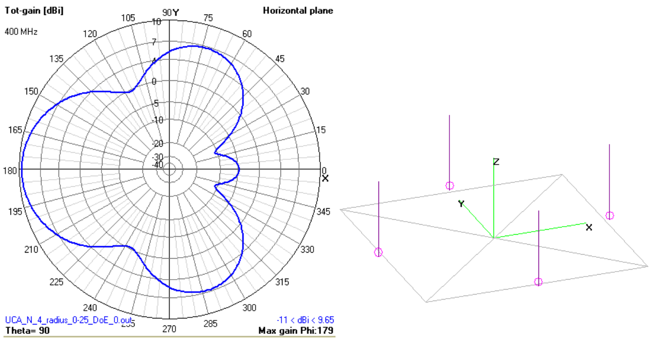
(b) Practical realisation of a single tracking unit with microcontroller

Fig. 1: Retrodirective RADAR with track hold

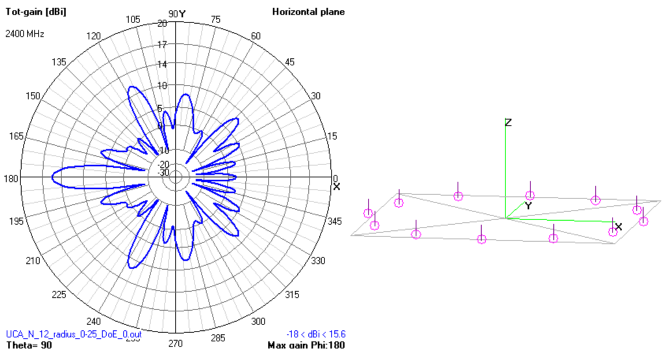
3 Tracking dynamics for a typical mobile scenario

Calculations are now shown, for a retrodirective RADAR mounted on a moving vehicle, which experiences a dropout from the target reflection, for a certain time period. The aim here is to determine, when the target reappears, if it is still within the half power beamwidth of the RADAR’s antenna array. This would mean that if the RADAR was able to “track hold” during a target reflection dropout, then a maximum beam (within a certain tolerance) would still be returned to the target during the period of the dropout in the reflected signal. This would have the advantage that a reacquisition would not be required when the target reappears. In addition, if the RADAR signal was also used to carry data, there would be no loss of transmitted data, during the period of loss of target reflection.

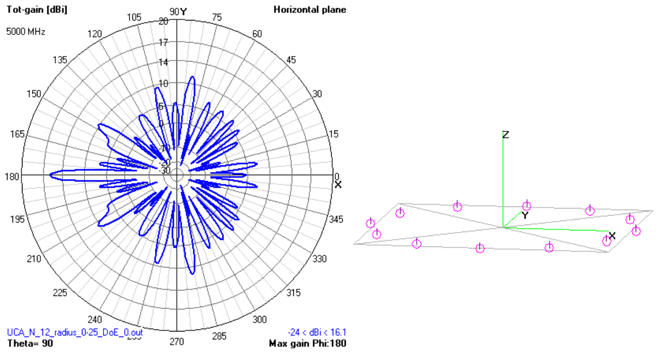
By considering the beamwidth of different antennas, at different frequencies, we estimate, if the reflected signal disappears, the time period for the retransmitted beam to reach the 3dB points. Three different antenna configurations are considered, at 400 MHz, 2.4 GHz and 5 GHz. Circular monopole arrays are used for the antenna configuration, as these offer 360° azimuthal coverage. Figure 2 (a-c) show the antenna array configurations. 3 dB beam widths are predicted to be 60°, 10° and 5° at 400 MHz, 2.4 GHz and 5 GHz respectively.



(a) 400 MHz, 4 Elements, Gain = 9 dBi, 3dB BW = 60°



(b) 2.4 GHz, 12 Elements, Gain = 15.6 dBi, 3dB BW = 10°



(c) 5 GHz, 12 Elements, Gain = 16.1 dBi, 3dB BW = 5°

Fig. 2: Retrodirective RADAR array configurations.

The calculations in this section are based on a retrodirective RADAR mounted on a vehicle experiencing a certain turning rate. Turning rates of up to 60°/s are used for the calculations, which are taken from typical specifications for mobile steerable antennas [8]. Using the predicted beamwidths from Figure 2, it is possible to calculate the maximum time (T) that a signal dropout from the target reflection can be experienced, before the signal moves beyond the 3dB beam width of the antenna array. This can be calculated from:

$$T = \frac{3dB\ beamwidth}{2(Turning\ Rate)} \quad (1)$$

Therefore if the target reflected signal re appears in less than this time period then it is assumed that the retrodirective RADAR has been able to maintain the retransmitted beam within 3dB, towards the target, during the drop out period. If this is the case, then a "track hold" function that can hold the target direction during a dropout will suffice, to maintain the retransmit signal to the target.

These calculations from equation (1) are plotted on the graph of Fig 3. From Fig 3 it can be seen that the target dropout time (T) varies from up to 6s for a turning rate of 5°/s at 400 MHz, to as low as 0.04s at 5 GHz at turning rate of 60°/s.

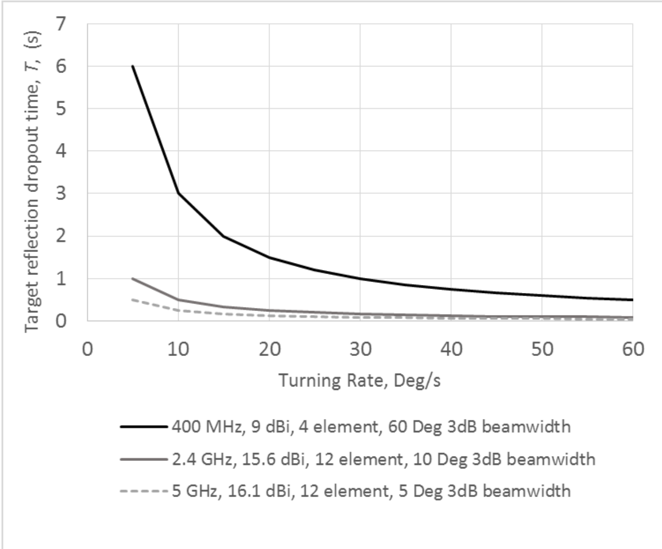


Fig. 3: Reflected signal dropout times Vs turning rate

Since hold times from PLL based retrodirective RADAR (ie no microcontroller in the tracking loop) are generally less than several milliseconds, the above clearly demonstrates the need for "track hold" circuits to provide a longer hold time. For lower frequency (eg 400 MHz), lower gain systems, a "track hold" circuit that simply maintains the transmit phase in the absence of RX signal is likely to be sufficient. From Fig 3, at 400 MHz, with the highest turning rate of 60°/s, the signal reflected to the target can be maintained within the 3 dB points for 0.5 s, ie the longest time that a dropout in the reflected signal can be experienced, before degradation of the reflected signal occurs.

For higher frequencies and higher gains (eg 2.4 GHz, 5 GHz), tighter beam widths mean that the retransmitted signal to target (when using track hold) can only be maintained for very short dropout periods of the reflected signal. At the highest turning rate of 60°/s, this equates to 80 ms at 2.4 GHz and 40 ms at 5 GHz. To enable the retransmitted signal to stay pointed at the target for longer dropouts of the reflected signal, one potential solution is the use of a "rate of change of phase" tracking circuit. This functionality has been added to the microcontroller in Fig 1 and has been shown practically to successfully track a rate of change of phase of 20°/s, which equates to a turning rate of 12.6°/s, when calculated for two antennas at $\lambda/4$ spacing.

4 Conclusions

This paper has demonstrated that the addition of a "track hold" circuit to a retrodirective RADAR (a feature that was not previously available) can allow the retransmitted signal to the target to reliably continue transmission, during dropouts in the reflected signal from the target. The calculations have shown that for a lower frequency, lower gain antenna array configuration (400 MHz, 4 elements) that the track hold circuit can maintain the retransmitted signal, within the 3 dB points of the antenna array, for 0.5 s, at a vehicle turning rate of 60°/s. This shows it is likely that a track hold circuit will suffice for lower frequency, lower gain systems. At higher frequencies and higher gains (eg 2.4 GHz, 5 GHz), the retransmitted signal to target (when using track hold) can only be maintained for 80 ms at 2.4 GHz and 40 ms at 5 GHz at a turning rate of 60°/s. This implies that, for the higher frequency scenario, that a "rate of change of phase" tracking circuit is required.

Acknowledgements

The authors would like to thank Mr Kieran Rainey for the construction of the circuits used for this work.

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